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GAMMA-RAY ABSORPTION AT HIGH REDSHIFTS AND THE GAMMA-RAY BACKGROUND

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ABSTRACT

We present results of a calculation of absorption of 10-500 GeV γ-rays at high redshifts (Salamon and Stecker, 1997). This calculation requires the determination of the high redshift evolution of the full spectral energy distribution of the intergalactic photon field. For this, we have primarily followed the recent analysis of Fall, Charlot & Pei. We give our results for the γ-ray opacity as a function of redshift out to a redshift of 3. We then give predicted γ-ray spectra for selected blazars and also extend our results on the background from unresolved blazars to an energy of 500 GeV. Absorption effects are predicted to significantly steepen the background spectrum above 20 GeV. Our absorption calculations can be used to place limits on the redshifts of γ-ray bursts. Our background calculations can be used to determine the observability of multi-GeV lines from dark matter (neutralino) particles.

INTRODUCTION

Absorption of γ-rays from blazars and extragalactic γ-ray bursts is strongly dependent on the redshift of the source (Stecker, De Jager & Salamon 1992). Stecker & De Jager (1997) have calculated the absorption of γ-rays at above 0.3 TeV at redshifts up to 0.54. The study of extragalactic absorption below 0.3 TeV at higher redshifts is a more complex and physically interesting subject. In order to calculate such absorption properly, one must determine the spectral evolution of galaxy starlight photons from the IR through the UV range out to high redshifts. Pei & Fall (1995) have devised a clever method for calculating stellar emissivity as a function of redshift, one which is consistent with all recent data. We adopt this method and extend it by calculating the additional effect of metallicity evolution on stellar emissivity. We then calculate the γ-ray opacity of the universe to stellar photons at various redshifts and apply our results to selected blazar spectra and the blazar background.

CALCULATION OF STELLAR EMISSIVITY

The basic idea of the Pei & Fall (1995) approach, which we follow, is to relate the star formation rate to the evolution of neutral gas density in damped Lyα systems and then to use the population synthesis models (Bruzal & Charlot 1993) to calculate the mean volume emissivity of the universe from stars as a function of redshift and frequency. Damped Lyα systems are believed to be either the precursors to galaxies or young galaxies themselves. It is in these systems that initial star formation probably took place, so there is a relationship between the mass content of stars and gas in these clouds. The results obtained by Fall, *et al.* 1996 show excellent agreement with observational data obtained by the Canada-France redshift survey group for redshifts out to 1 (Lilly, *et al.* 1996) and are consistent with lower limits obtained on the emissivity at higher redshifts (Madau 1996). The stellar emissivity is found to peak between a redshift of 1 and 2 which is consistent with the results of ongoing observations from both the Hubble and Keck telescopes. We have made one significant modification to the calculations of Fall, *et al.* (1996). We have attempted to account for the significantly lower metallicity of early

generation stars at higher redshifts which results in increased emission at shorter wavelengths and lowered emission at longer wavelengths. In order to estimate this effect, we have used the results of Worthey (1994) and moderately extrapolated them to both lower and higher wavelengths (Salamon & Stecker 1997). We have also considered the effect of dust opacity and have assumed a reasonable escape factor to account for the fact that a small fraction of Lyman continuum photons escape from galaxies unattenuated by stars and dust. The effect of this escape factor on our subsequent opacity calculations is negligible, since there are not enough ionizing photons in intergalactic space to provide a significant opacity to multi-GeV γ-rays. Because the metallicity corrections are less certain for the more massive stars ($M > 2M_{\odot}$), our metallicity-corrected UV radiation density should be viewed as an upper limit.

OPACITY OF THE UNIVERSE TO GAMMA-RAYS

Once the spectral energy density distribution of stellar photons in intergalactic space as a function of redshift is determined, the opacity of the universe to γ-rays as a function of γ-ray energy and redshift can be calculated (Stecker, *et al.* 1992). The basic processes which causes the attenuation of γ-rays is the interaction of a γ-ray with a starlight photon which results in the production of an electron-positron pair. Our results indicate that γ-rays above an energy of $\sim$15 GeV will be attenuated if they are emitted at redshifts greater than or equal to $\sim$3. The γ-ray burst observed by EGRET on 17 Feb 1994 contained a photon of energy $\sim$18 GeV. Figure 1 shows the calculated opacity as a function of γ-ray energy for various source redshifts, with and without the metallicity correction included; the true opacities likely lie between the values shown in the left and right halves of Fig. 1.

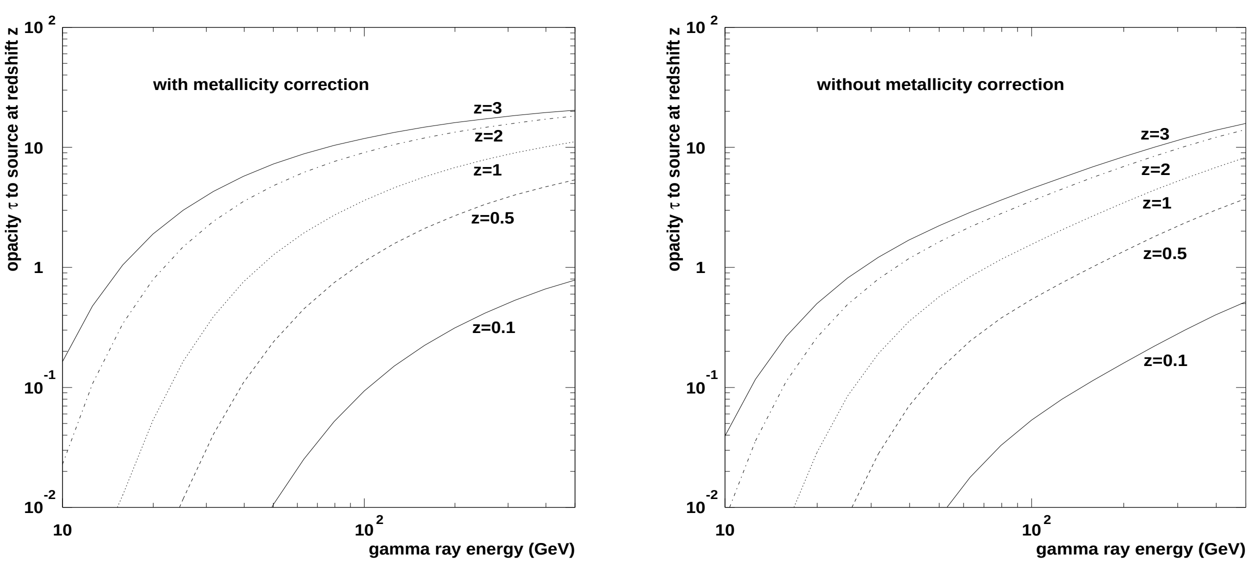

Figure 1: High energy γ-ray opacities calculated with and without metallicity correction factor included.

Because the stellar emissivity peaks between a redshift of 1 and 2, there is little increase in the γ-ray opacity when one goes to redshifts greater than 2. This weak dependence indicates that the opacity is not determined by the initial epoch of galaxy formation (which may be at $z \geq 5$), contrary to the speculation of MacMinn & Primack (1996).

EFFECT OF ABSORPTION ON BLAZARS AND THE BACKGROUND

Figure 2 shows the attenuation of γ-ray spectra resulting from the opacities given in Figure 1 for the blazar sources 1633+382 ($z = 1.81$), 3C279 ($z = 0.54$), 3C273 ($z = 0.15$), and Mrk421

($z = 0.031$). The solid (dashed) lines result from the opacities shown in left (right) half of Figure 1. The redshift dependence of the break energies is evident, as is the absence of any breaks below 10 GeV. Future measurements of blazar spectral break energies will discriminate between models of extragalactic extinction (such as this one) and those involving cutoffs *intrinsic* to the source.

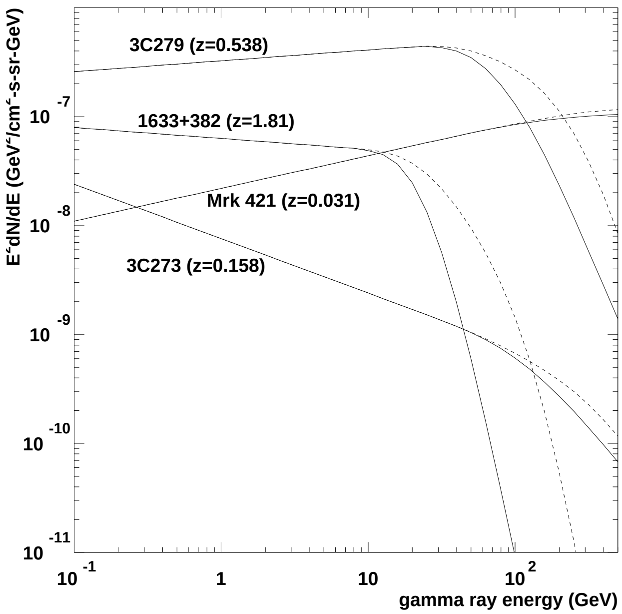

Figure 2: High energy γ-ray spectra of selected blazars attenuated according to the opacities of Figure 1. The solid (dashed) lines correspond to the opacities calculated with (without) the metallicity correction.

Figure 3 shows the effect of absorption on the extragalactic γ-ray background computed using the unresolved blazar model of Stecker & Salamon (1996). The solid (dashed) lines correspond to the metallicity correction being included (neglected) in the opacity calculation. The two families of curves correspond to point source sensitivities of EGRET (top curves) and GLAST (bottom curves). (A better point source sensitivity results in the reduction in the number of *unresolved* γ-ray sources which contribute to the γ-ray background.) Also shown are the preliminary EGRET data on the extragalactic γ-ray background spectrum (Fichtel 1996). The cutoff observed beyond $\sim$20 GeV reduces the effect of the extragalactic γ-ray background on searches for γ-ray lines from neutralino-neutralino annihilation in the galactic halo, should the extragalactic γ-ray background be due to unresolved flat-spectrum radio quasars.

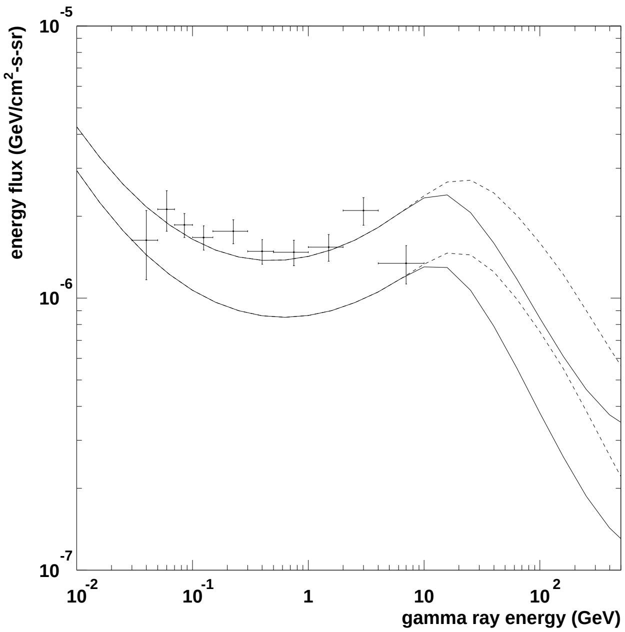

Figure 3: The extragalactic γ-ray background, calculated with the model of Stecker and Salamon (1996), and attenuated with the opacities of Fig. 1. (See text.)

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REFERENCES

Bruzal, A. G. & Charlot, S. 1993, *Astrophys. J.* **405**, 538.

Fall, S. M., Charlot, S. & Pei, Y. C. 1996, *Astrophys. J.* **402**, 479.

Fichtel, C. E. 1996, *Astron. Astr. Suppl.* **120**, 23.

Lilly, *et al.* 1996, *Astrophys. J. (Lett.)* **460**, L1.

MacMinn, D, & Primack, J. 1966, *Space Sci. Rev.* **75**, 413.

Madau, P. *et al.* 1996 *MNRAS* **283**, 138.

Pei, Y. C. & Fall, S. M., 1995, *Astrophys. J.* **454**, 69.

Salamon, M. H. & Stecker, F. W. 1997, submitted to *Astrophys. J.*

Stecker, F. W. & De Jager, O. C. 1997, *Astrophys. J.* **476**, 712.

Stecker, F. W., De Jager, O. C. & Salamon, M. H. 1992, *Astrophys. J. (Lett.)* **390**, L49.

Stecker, F.W., and Salamon, M.H. 1996, *Astrophys. J.* **464**, 600.